



**U.S. Army Aviation Life Support Equipment
Retrieval Program: Head and Neck Injury
Among Night Vision Goggle Users
in Rotary-Wing Mishaps**

By

Samuel G. Shannon

and

Kevin T. Mason

Aircrew Protection Division

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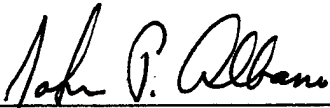
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Reviewed:



JOHN P. ALBANO
MAJ, MC, SFS
Director, Aircrew Protection
Division

Released for publication:



JOHN A. CALDWELL, Ph.D.
Chairman, Scientific Review
Committee



CHERRY L. GAFFNEY
Colonel, MC, SFS
Commanding

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injury risk (RR=2.01, CI95=1.58,2.57). For crewmembers wearing the aviator's night vision imaging system (ANVIS), the risk of head and/or neck, head only, or neck only injury was not statistically greater than crewmembers not wearing NVGs (RR=1.22, CI95=0.94,1.58).

Aircrew wearing the older AN/PVS-5 were at increased risk for head/neck injury during a rotary-wing mishap, while ANVIS users with the ANVIS break-away feature were not at increased risk for head/neck injury.

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Introduction

The high risk of head injury associated with U.S. Army rotary-wing mishaps was reported over a decade ago (Shanahan, 1985). Some fundamental questions about the etiology of traumatic head injury in rotary-wing mishaps remain unresolved. Night vision goggles (NVGs) are used frequently by U.S. Army aircrews. NVGs attached to aircrew helmets increase head-supported mass and shift the center of gravity of the helmet/NVG system above that of the head, resulting in a theoretical increased risk of head and neck injuries if the NVG device were retained in a dynamic mishap situation. The relationship between NVG use and head/neck injury risk is unknown.

This is a 10-year retrospective study of the association between NVG use and traumatic head/neck injuries among U.S. Army aircrew members in rotary-wing mishaps. The correlates of impact velocity are examined to assess the potential contribution of biomechanics and aircraft design on the relationship between NVG use and head/neck injury. Identification of risk factors, and their possible determinants, provide a basis for comments on preventive strategies from a medical and engineering perspective.

Methods

Cohort selection

The U.S. Army Automated Safety Management System (ASMIS), maintained by the U.S. Army Safety Center, Fort Rucker, Alabama, contains data on U.S. Army aircraft mishaps. A query identified 1,193 class A, B, or C rotary-wing mishaps that occurred during a 10-year period for calendar years 1985 through 1994. Class A mishaps were the most serious in the degree of airframe damage and human injury. The ASMIS data analyzed from these mishaps included aircraft type, accident class, survivability, impact terrain, and five kinematic parameters at impact: horizontal and vertical velocity, and roll, pitch, and yaw angles. For each crewmember, ASMIS data were abstracted on their relative position within the aircraft and NVG use. ASMIS fields describing the severity of injury, the body region affected, and general information on causation were abstracted to generate body-region specific injury rates.

Mishaps that occurred during ground taxiing, in-flight wire or other obstacle strikes for which the aircraft subsequently landed safely, where personnel fell from the aircraft, or where ground personnel were struck by the aircraft or rotor system were eliminated, as well as those involving the TH-55 and TH-67 primary training helicopters. The AH-64 Apache mishaps were also eliminated since these aircraft have a unique helmet-mounted vision system. Seven additional mishaps were dropped because the type of NVG could not be determined. Injury analysis was limited to cockpit aircrew members, since their restraint systems and aviation life support equipment (helmets, fire-retardant flight suits, etc.) were standardized across helicopter types.

The final analytical database consisted of the injury data from 704 crewmembers from 357 mishaps where the aircraft impacted the ground with airframe damage and/or injuries.

Data analysis

For simplicity, each crewmember's body was divided into six anatomical regions: head, neck, chest, abdomen, upper extremities, and lower extremities. Each injury was recoded to reflect the body region affected. The numbers of injuries were summed for each body region and incidence rates were calculated for NVG wearers and nonwearers. At first, all traumatic injuries were counted. Later, thermal and chemical burns of the head and neck were eliminated, as these injuries were not likely related to NVG use.

The incidence of injury among the crewmembers was determined by the number of injured crewmembers divided by the total number of crewmembers in the study. The relative risk was used to quantify the association between NVG use and injury. Categorical data were analyzed using either the Chi-square or Mantel-Haenszel procedure (SAS, 1989). Continuous data were analyzed using the Student's t-Test (Hatcher and Stepanski, 1994). When the expected frequency of any cell in a 2x2 table was zero, results were not reported.

Multiple logistic regressions were fitted to obtain estimates of the risk of injury, adjusted for multiple factors that might contribute to the occurrence of injury. A variable was entered into the model only if its addition had a significant contribution to the model at a p value of <0.05 . Each variable was assessed through the Wald test. The models were compared using the likelihood ratio test. The final model goodness of fit was assessed by the Hosmer-Lemeshow test (Hosmer and Lemeshow, 1989). Ninety-five percent confidence intervals were computed on the relative risks derived from the regression coefficients and their respective standard errors.

Covariates in these regressions included the aircraft series, crewmember position in the aircraft, and each of the kinematic parameters listed previously. However, in the final analyses, adjustment for kinematic differences was accomplished simply by including the ASMIS variable "survivability" as a covariate in the regression. During the investigation of an aircraft mishap, the U.S. Army Accident Investigation Board determines whether the mishap was survivable, partially-survivable, or nonsurvivable. This determination is based on the estimated mechanical forces experienced by, and the observed livable space remaining for the crewmembers. If the mechanical forces were within human tolerances and the aircraft's structure maintained livable space, the mishap is said to be survivable. If the mechanical forces were beyond human tolerances, or the livable space was not adequate to assure survival, the mishap is said to be nonsurvivable. Otherwise, the mishap is said to be partially survivable.

Although potentially important, the authors did not find an association between the ASMIS fields reflecting injury causation and the observed injury risk. This was not unexpected, as causation implies uncertainties since the observations of the investigators were seldom confirmed in the laboratory. Moreover, mishaps where causation is known or can be proven may be special

cases, reflecting a rare set of conditions. Therefore, the authors elected to drop ASMIS fields reflecting injury causation from the final analysis.

Results

Table 1 describes the classification parameters for ASMIS Class A through C mishaps. The proportion of mishaps for each aircraft type by ASMIS classification is shown in Table 2. The CH-47, OH-58, and UH-60 have significantly higher proportions of Class A mishaps than do the OH-6/AH-6 ($p < 0.05$). By aircraft, the proportion of Class A mishaps is highest in the CH-47, followed by the OH-58A-C, UH-60, UH-1, OH-58D, AH-1, and OH-6/AH-6.

Table 1.
U.S. Army aircraft mishap classification.

Class	Damage cost	Description
A	\$1,000,000 or more	Aircraft destroyed; fatality or permanent total disability
B	\$200,000-\$999,999	Permanent partial disability, 5 or more personnel hospitalized
C	\$10,000-\$199,000	Injury or illness results in lost work time or disability

Table 2.
Proportion of mishaps for each aircraft type by ASMIS classification.

Aircraft	Class A mishap		Class B mishap		Class C mishap		Overall
	N	%	N	%	N	%	
AH-1	25	47.2	14	26.4	14	26.4	53
CH-47	9	75.0	3	25.0	0	0.0	12
OH-58A/C	65	71.4	3	3.3	23	25.3	91
OH-58D	11	55.0	6	30.0	3	15.0	20
OH6/AH-6	11	44.0	4	16.0	10	40.0	25
UH-1	65	59.6	13	11.9	31	28.4	109
UH-60	32	68.1	8	17.0	7	14.9	47
Overall	218	61.1	51	14.3	88	24.6	357

A breakdown of survivability by both the numbers of aircraft and numbers of cockpit crewmembers is shown in Table 3. When the distribution of survivability was analyzed by aircraft type, there was no significant pattern to the distribution. The highest proportion of

nonsurvivable mishaps occurred in the CH-47 (25.0 percent), followed by the UH-60, OH-58D, OH-58, OH6/AH-6, AH-1, and UH-1 (13.7 percent).

Table 3.
Proportion of mishaps for each aircraft type by survivability classification
and the number of cockpit crew involved.

Aircraft	Survivable		Partially-survivable		Nonsurvivable		Overall	
	Aircraft	Crew	Aircraft	Crew	Aircraft	Crew	Aircraft	Crew
AH-1	40 (75.5)	80	5 (9.4)	10	8 (15.0)	16	53	106
CH-47	8 (66.7)	16	1 (8.3)	2	3 (25.0)	6	12	24
OH-58	67 (73.6)	129	7 (7.7)	13	17 (18.7)	34	91	176
OH-58D	14 (70.0)	28	2 (10.0)	4	4 (20.0)	8	20	40
OH/AH-6	20 (80.0)	39	1 (4.0)	2	4 (16.0)	7	25	48
UH-1	84 (77.1)	166	10 (9.2)	20	15 (13.7)	30	109	216
UH-60	29 (61.7)	58	7 (14.9)	14	11 (23.4)	22	47	94
N	262 (73.4)	516	33 (9.2)	65	62 (17.4)	123	357	704

Of the 704 cockpit aircrew members examined, 403 (57.2 percent) suffered some degree of injury during the mishap. Of these 403, 120 were killed, 28 were permanently disabled, and 164 lost workdays due to their injuries. Of the 403 crewmembers who were injured, 250 (62.0 percent) suffered injuries to the head or neck region.

A disproportionate number of cockpit aircrew members in nonsurvivable mishaps had head and/or neck injuries (87.0 percent) compared to those in survivable mishaps (19 percent). Therefore, the ASMIS variable, survivability, was used as a covariate in multivariate regressions to control for differences in survivability related to kinematic parameters.

As shown in table 4, the use of NVGs was associated with an increased risk of head and neck injury. After controlling for the survivability of the mishap, NVG users were 45 percent more likely to suffer a head or neck injury compared to non-NVG users (relative risk=1.45, 95 percent confidence interval 1.17 to 1.79). There was evidence of risk modification with the newer aviator's night vision imaging system (ANVIS) goggles compared to the older AN/PVS-5 goggles. Crewmembers wearing ANVIS goggles tended to have a higher, but nonsignificant, risk of head or neck injury compared with non-NVG users. By contrast, crewmembers using the older AN/PVS-5 goggles were twice as likely to suffer a head or neck injury compared to non-NVG users, after controlling for the type of aircraft (UH-60 Black Hawk versus all other aircraft series) and mishap survivability (potentially-survivable versus nonsurvivable). More

significantly, AN/PVS-5 users were 162 percent more likely to suffer a head injury than a nonuser (relative risk=2.62, 95 percent confidence interval 1.32 to 4.68). The table in the appendix provides the data set for these statistics.

Table 4.
Relative risk of injury comparing NVG users to non-users, controlling for survivability rating.

Injury pattern	Relative risk (CI _{0.95})		
	Any NVG	AN/PVS-5	ANVIS
Head and/or neck	1.45 (1.17,1.79)	2.01 (1.58,2.57)	1.22 (0.94,1.58)
Head only	1.76 (1.15,2.67)	2.62 (1.32,4.68)	1.51 (0.94,2.57)
Neck only	1.17 (1.12,2.02)	2.10 (1.75,2.49)	1.38 (0.93,2.24)

Discussion

A possible source of bias in the previous analyses is a difference in the mission profiles flown by NVG users, such as nap-of-the-earth (NOE) missions. Mishaps occurring during NOE flights are likely to have different kinematic parameters than mishaps occurring during other missions. To test this hypothesis, kinematic parameters from NVG mishaps were compared with those of other mishaps. As shown in table 5, the student's t-Test was used in univariate analyses to compare impact horizontal and vertical velocities, roll-pitch-yaw angles, and longitudinal and lateral G-force between the two groups of mishaps: those where NVG were worn, and all other mishaps. Statistically significant differences were observed between horizontal velocity and pitch angle at primary impact between the two groups of mishaps ($p < 0.05$). In comparison, a previous study modeling injury risk (Shannon and Shanahan, 1993) concluded that vertical and horizontal velocity, and pitch and roll angles at primary impact were associated with the degree of injury in Army rotary-wing mishaps involving the UH-1 and UH-60 aircraft.

As a confirmation of these observations using multivariate analysis, a two-way analysis of variance (ANOVA) was used to control for differences in flight characteristics between the UH-60 series aircraft, and the AH-1, AH-6/OH-6, OH-58A-C/OH-58D, and UH-1 aircraft. For simplicity (and to decrease the degrees of freedom in the model), mishaps involving the CH-47 series aircraft were excluded from these analyses. The ANOVA F-test showed that after controlling for differences in flight characteristics between the UH-60 and other aircraft, impact horizontal velocity ($F=3.92$, $df=1$, $p=0.049$) and pitch angle ($F=4.96$, $df=1$, $p=0.027$) were significantly higher in mishaps where the crewmembers wore NVGs. Therefore, the impact kinematics of NVG mishaps are likely related to mission profile and aircraft type.

Table 5.

A comparison of kinematic parameters between mishaps with and without NVGs being worn by at least one cockpit aircrew member.

Impact kinematic parameters	NVGs in use at time of mishap				Student's <i>t</i>	
	Yes		No		<i>t</i>	<i>p</i>
	Mean	STD	Mean	STD		
Vertical velocity (ft/sec)	17.61	23.01	24.00	35.59	-1.496	0.138
Horizontal velocity (ft/sec)*	30.87	45.66	43.93	50.71	-2.122	0.035
Roll angle (degrees)	-1.75	38.43	-7.94	35.56	1.271	0.205
Pitch angle (degrees)*	-2.20	26.09	-10.22	37.68	2.141	0.033
Yaw angle (degrees)	7.86	53.37	17.39	61.31	-1.213	0.226
Longitudinal G-force	11.26	24.20	16.81	29.66	-1.418	0.159
Lateral G-force	6.21	12.83	10.86	23.83	-1.503	0.137

* Significant, $p < 0.05$

Conclusions

The authors believe that this is the only study to report a positive association between NVG use and injury risk. Despite the small number of mishaps where crewmembers were wearing NVGs, the authors were able to control for the possible confounding effects of differences in impact kinematics by stratifying the analyses by NVG type and ASMIS survivability codes. Use of the older AN/PVS-5 NVGs were associated with higher risk of head and neck injury. Surprisingly, we did not observe any significant difference in injury between crewmembers wearing ANVIS and crewmembers not wearing NVGs. The reduced injury risk for ANVIS was likely due to the break-away feature built into the ANVIS helmet mount.

This study shows the value of using mishap analysis through the U.S. Army Aeromedical Research Laboratory's Aviation Life Support Equipment Retrieval Program to enhance our understanding of injury epidemiology in rotary-wing mishaps. Even with improvements in protection afforded the wearer of the new HGU-56/P aircrew member helmet when compared to the older SPH-4, the level of protection afforded by the helmet is dictated by the laws of physics. Adding helmet-mounted devices adversely changes the helmet system mass properties. Epidemiological and biomechanical models must be developed to assess the relationship between use of specific helmet-mounted devices and the resultant risk of injury to the user. Helmet-mounted devices such as NVGs must be designed to decrease the risk of head and neck injury.

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Appendix.

Survivability data set

Injury patterns stratified by NVG type and mishap survivability rating.

NVG Type	Body region	ASMIS Survivability Code			Overall (n=704)
		Survivable (n=516)	Partially- survivable (n=65)	Non-survivable (n=123)	
AN/PVS-5 n=48	Head/neck	10 (38.5)*	7 (87.5)*	14 (100)	31 (64.6)*
	Head only	8 (30.8)*	5 (62.5)	13 (92.9)	26 (54.2)
	Neck only	2 (7.7)	5 (50.0)	5 (35.7)	1 (22.9)*
ANVIS n=120	Head/neck	17 (21.8)*	9 (64.3)*	21 (75.0)	47 (39.2)*
	Head only	14 (18.0)*	9 (64.3)	20 (71.4)	43 (35.8)
	Neck only	6 (7.7)	1 (7.1)	3 (10.7)	10 (8.3)*
No NVG n=536	Head/neck	72 (17.5)*	28 (65.1)*	72 (88.9)	172 (32.1)*
	Head only	48 (11.7)*	27 (62.8)	64 (79.0)	139 (25.9)
	Neck only	33 (8.0)	9 (20.9)	25 (30.9)	67 (12.5)*
Overall N=704	Head/Neck	99 (19.2)	44 (67.7)	107 (95.1)	250 (35.5)
	Head Only	70 (13.6)	41 (63.1)	97 (78.9)	208 (29.6)
	Neck Only	41 (7.9)	14 (21.5)	33 (26.8)	88 (12.5)

* Significant $p < 0.05$